TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 69, Issue Special III, July, 2026

SIMULATION-BASED PREDICTION OF MANET PERFORMANCE IN DYNAMIC NETWORKS

Robert PAPA, Claudia ENACHE, Annamaria SÂRBU

Abstract: *Mobile Ad Hoc Networks (MANETs) operate in dynamic environments where node mobility continuously alters network topology. While simulation-based studies provide extensive measurements, most remain descriptive and do not support performance prediction. This paper proposes a lightweight, simulation-driven approach for deriving predictive trends from controlled experiments. Using GloMoSim, four scenarios are defined in which all parameters are fixed except node mobility, which increases from static to highly dynamic regimes. Employing the Ad hoc On-Demand Distance Vector (AODV) routing protocol and multiple Constant Bit Rate (CBR) flows over the User Datagram Protocol (UDP), the study evaluates packet delivery ratio, delay, throughput, and routing overhead. The results reveal structured relationships between mobility and performance, enabling empirical prediction of operational regimes and trade-offs prior to deployment.*

Keywords: *MANET, GloMoSim, mobility, performance evaluation, simulation, prediction, AODV.*

1. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) enable communication in environments where fixed infrastructure is unavailable, unreliable, or impractical. As a foundational technology for many emerging and disruptive applications, MANETs are becoming increasingly critical in modern communication ecosystems. Such networks are formed dynamically by mobile nodes that cooperate to forward packets without relying on centralized coordination [1-2]. This paradigm is fundamental for a wide range of applications, including disaster response, vehicular communications, autonomous systems, and temporary field deployments [3-5]. However, the same characteristics that make MANETs attractive—mobility, decentralization, and rapid topology changes—also make their behavior difficult to predict and control [2].

A large body of research has investigated MANET performance under various conditions, focusing on routing protocols, traffic patterns, and mobility models typically using network simulators such as NS-2, NS-3, OMNeT++, INET, or QualNet [6-8]. Most existing studies rely on simulation to evaluate metrics such as packet delivery ratio, end-to-end delay, throughput, or routing overhead. While these works provide valuable insights into protocol behavior and relative performance (e.g., comparing AODV, DSR, DSDV, OLSR, AOMDV, and others under specific traffic and mobility settings) they are often limited to reporting performance values for fixed scenarios defined by particular node densities, speeds, traffic loads, or mobility models [6,7]. As a result, network designers and practitioners are left with extensive empirical data but little guidance on how to anticipate network behavior when conditions (such as node speed, pause time, or traffic intensity) change beyond the studied configurations [8].

In dynamic environments, even small variations in node mobility can lead to significant performance degradation due to more frequent route breaks, increased control traffic, and higher packet loss, which are repeatedly observed when varying node speed, pause time, or mobility patterns in simulation-based evaluations [6,7,9]. The lack of predictive capability complicates the

planning and deployment of MANET-based systems, as the expected quality of service cannot be estimated in advance [7,10]. This motivates the need for approaches that move beyond isolated measurements and toward systematic performance prediction based on controlled experiments and parameter sensitivity analyses, as suggested by recent comparative and heterogeneous MANET studies that systematically vary node types, mobility, and traffic to better understand performance trends [8,10].

This paper addresses this gap by proposing a simulation-based methodology for predicting MANET performance trends under varying mobility conditions. Using the GloMoSim simulator, a set of controlled scenarios is defined in which all network parameters are kept constant except for node speed. By analyzing how key performance indicators evolve across these scenarios, empirical relationships between mobility and network behavior are derived. The goal is not to provide exact analytical formulas, but to extract practical prediction trends that can support informed design decisions paving the way towards a lightweight and reproducible framework for transforming raw simulation results into predictive performance models.

2. RELATED WORK

2.1 Simulation of MANETs

MANET research has traditionally relied on a combination of analytical modeling and simulation-based evaluation to understand the behavior of infrastructure-less networks under mobility and resource constraints. Because real-world experimentation at scale is costly and difficult to reproduce, simulation remains a widely adopted approach for testing routing strategies, traffic patterns, and mobility conditions. Hogie *et al.* provide an extensive overview of MANET simulation practices and tools, highlighting why simulation is often preferred over testbeds and emphasizing the importance of scenario reproducibility and controlled parameter variation for meaningful evaluation [11].

2.2 Routing Protocol Performance Evaluation

A substantial portion of the literature focuses on performance evaluation of routing protocols using classical metrics such as packet delivery ratio, end-to-end delay, throughput, and routing overhead. For example, Chavan *et al.* compare AODV and DSDV and report differences across these metrics, noting that protocol design choices (reactive versus proactive behavior) lead to distinct trade-offs in overhead, delivery, and delay [12]. Such comparative studies are valuable for protocol selection, but they typically present results as point measurements under specific scenario settings rather than aiming to generalize performance trends across an operational range of conditions.

2.3 Impact of mobility and network parameters

Another well-studied factor is node mobility, which directly affects topology stability and routing dynamics. Ismail and Hassan evaluate AODV under multiple mobility speeds and show a consistent degradation of throughput and packet delivery ratio as speed increases, demonstrating that mobility is a primary driver of performance reduction in both homogeneous and heterogeneous MANET settings [13]. This line of work supports the need for scenario designs in which mobility parameters are systematically varied while other configuration elements remain fixed, enabling clearer attribution of observed performance changes to mobility alone.

Beyond mobility, researchers also explore how network and radio configuration parameters shape MANET performance. Sharma *et al.* investigate the effect of transmission power variation on MANET behavior and evaluate performance using metrics such as packet delivery fraction and normalized routing load, illustrating how PHY/MAC-level choices and routing mechanisms interact to influence end-to-end outcomes [14]. Similarly, energy-aware routing studies emphasize the impact of constrained node resources and the cost of routing control operations on network lifetime and throughput [15]. These works broaden the performance perspective beyond pure packet metrics by connecting routing decisions with

resource limitations that are intrinsic to ad hoc systems.

2.4 Application-Driven MANET Studies

MANETs are also frequently motivated by application-driven scenarios where infrastructure is disrupted or unavailable. In disaster recovery contexts, Mahiddin and Sarkar discuss MANET suitability for rapidly re-establishing communication and study network throughput issues related to congestion and mobility, proposing improvements at the gateway selection level [13].

While this application framing differs from protocol-centric comparisons, it similarly relies on simulation evidence and typically reports performance improvements within the tested configurations.

2.5 Limitations of Existing Approaches

Finally, some works pursue theoretical performance characterization, particularly for delay-related behavior in specialized MANET communication models. Yang *et al.* develop a Markov-chain framework to derive analytical expressions for multicast delay under cooperative multicast schemes, complementing simulation validation with formal analysis [16]. Although such approaches offer deeper theoretical insight, they often target specific traffic and routing abstractions and may not directly translate into practical prediction procedures for general MANET deployments evaluated through network simulators.

Overall, prior studies provide extensive evidence that MANET performance depends strongly on mobility, routing strategy, and configuration parameters, and simulation is a dominant method for evaluating these effects. However, much of the existing literature remains primarily descriptive, reporting metrics for discrete scenarios rather than extracting predictive performance trends that can estimate expected behavior when conditions change (e.g., increasing mobility speed).

This paper builds on established simulation-based evaluation practices and addresses this gap by structuring a controlled set of GloMoSim scenarios to derive empirical, reproducible prediction relationships between node mobility and key MANET performance indicators.

3. SIMULATION ENVIRONMENT

3.1 GloMoSim Framework

All experiments are conducted using GloMoSim, a discrete-event simulator designed for large-scale wireless and mobile network studies. Its modular architecture models the network protocol stack from the physical layer to the application layer and enables controlled evaluation of routing, mobility, and traffic behavior. In this work, identical simulation configurations are applied across all scenarios, with node mobility being the only varying parameter, ensuring reproducible and directly comparable results.

3.2 Network Configuration

The simulated network consists of 25 mobile nodes uniformly distributed within a 500 m × 500 m area. All nodes are equipped with identical wireless interfaces and operate over a shared radio channel.

The Ad hoc On-Demand Distance Vector (AODV) protocol is used as the routing mechanism in all scenarios, providing on-demand route discovery and maintenance in dynamic topologies.

Each simulation run has a duration of 300 seconds. Physical and MAC layer parameters are kept constant throughout all experiments in order to isolate the impact of mobility on network performance.

3.3 Traffic Model and Performance Metrics

Application-layer traffic is generated using Constant Bit Rate (CBR) sources over the User Datagram Protocol (UDP). Four independent CBR flows between fixed source–destination pairs are defined and remain unchanged across all scenarios.

Network performance is evaluated using Packet Delivery Ratio, end-to-end delay, throughput, and routing overhead, providing a balanced assessment of both data-plane efficiency and control-plane cost.

4. EXPERIMENTAL DESIGN

The experimental design follows a controlled-variation methodology in which a single dominant parameter—node mobility—is systematically modified while all other network and traffic parameters remain constant. This approach aims to isolate the effect of mobility on MANET performance and to prevent confounding influences introduced by simultaneous changes in topology, density, or traffic load.

The network size and spatial dimensions are deliberately kept moderate, with 25 nodes deployed over a 500 m × 500 m area. This configuration ensures a multi-hop communication environment while preserving a relatively stable node density across all scenarios. Increasing both the number of nodes and the simulation area would introduce additional degrees of freedom related to connectivity and path length, making it difficult to attribute performance variations exclusively to mobility. By fixing network scale and density, the experiment maintains a clear causal relationship between node movement and observed performance degradation.

All scenarios share identical routing, traffic, and physical-layer configurations. The Ad hoc On-Demand Distance Vector (AODV) protocol is used in every case, and four constant bit rate UDP flows remain active between fixed source–destination pairs. The only parameter that differs between scenarios is the mobility profile of the nodes, modeled using a random waypoint strategy with scenario-specific speed ranges and pause times.

The four experimental scenarios are summarized in Table 1.

Table 1

Mobility scenarios and configuration parameters

Scenario	Mobility Level	Speed Range (m/s)	Pause Time (s)
S0	Static baseline	0	-
S1	Low mobility	1-5	60
S2	Moderate mobility	5-10	30
S3	High mobility	10-20	10

Scenario S0 represents a fully stable topology in which nodes remain stationary throughout the entire simulation, providing a reference baseline for ideal routing conditions. Scenario S1 introduces low, pedestrian-level mobility, characterized by slow movement and long pause times, resulting in mildly dynamic topologies. Scenario S2 models moderate mobility with reduced pause intervals, reflecting environments where nodes move more frequently and route stability decreases. Finally, Scenario S3 represents highly dynamic conditions, combining high node speeds with very short pause times, leading to frequent link disruptions and rapid topology changes. Together, these scenarios form a continuous mobility spectrum from static to highly dynamic network behavior.

By structuring the scenarios as a monotonic progression in both speed and pause-time aggressiveness, the experimental framework creates a continuous mobility spectrum from static to highly dynamic behavior. This design enables the extraction of performance trends and supports the derivation of empirical prediction relationships between mobility intensity and MANET performance indicators.

5. RESULTS AND DISCUSSIONS

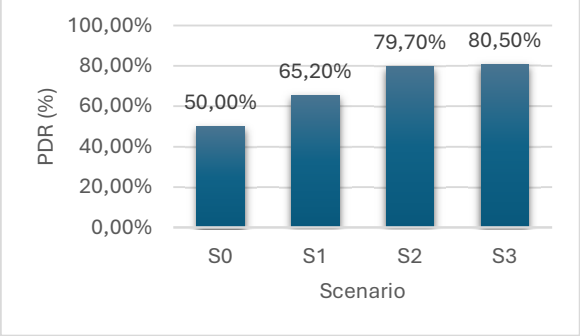


Fig. 1. Packet Delivery Ratio vs Scenario

This section presents and discusses the impact of node mobility on MANET performance by jointly analyzing packet delivery ratio, end-to-end delay, throughput, and routing overhead across the four mobility scenarios. Since all network and traffic parameters are kept constant and only mobility is varied, the observed trends directly reflect the influence of topology dynamics.

Packet Delivery Ratio (PDR) shows a clear improvement as mobility increases from the static scenario to moderate mobility levels. In the static case (S0), the network achieves a PDR of 50%, whereas scenarios with node movement reach values close to 80% in S2 and S3. PDR is computed as the ratio between the total number of data packets successfully received at the application layer and the total number of packets transmitted by the CBR sources:

$$PDR = \frac{\sum_{i=1}^{K} N_{received}^{(i)}}{\sum_{i=1}^{K} N_{sent}^{(i)}} \quad (1)$$

where $N_{received}^{(i)}$ and $N_{sent}^{(i)}$ denote the total number of packets successfully received and transmitted, respectively, for flow i at the application layer and and K represents the total number of CBR flows defined in the scenario.

This trend suggests that moderate mobility can enhance connectivity by allowing nodes to form more favorable multi-hop paths over time. However, the limited increase between S2 and S3 indicates a saturation region in which further mobility no longer significantly improves delivery performance.

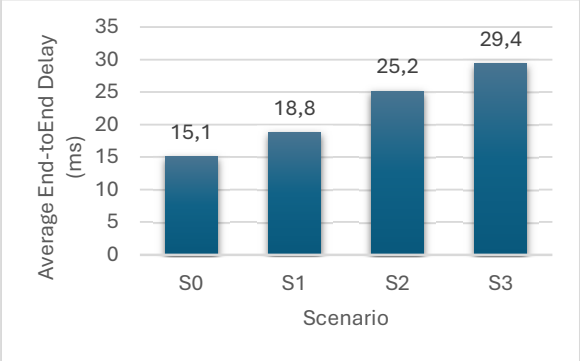


Fig. 2. Average End-to-End Delay vs Scenario

In contrast, the average end-to-end delay increases monotonically with mobility. Delay values rise from approximately 15.1 ms in the static scenario to nearly 29.4 ms under high mobility. The average delay is calculated as the arithmetic mean of the delays reported by all CBR receiver:

$$AvgDelay = \frac{1}{K}\sum_{i=1}^{K} Delay_i \quad (2)$$

where K denotes the number of CBR flows and $Delay_i$ represents the delay associated with flow. Since all CBR flows are configured with identical transmission parameters and duration, the arithmetic mean provides a representative estimation of the overall end-to-end delay. This increase reflects the growing frequency of route breakages and rediscovery operations required by the reactive routing protocol, which introduce additional buffering and processing delays.

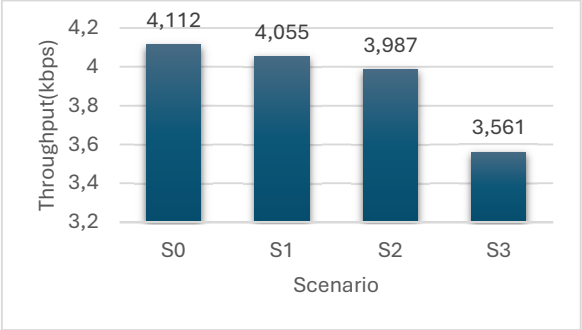


Fig. 3. Average Throughput vs Scenario

Throughput exhibits a gradual degradation as mobility intensifies. While the static and low-mobility scenarios maintain throughput values slightly above 4 kbps, high mobility (S3) results in a noticeable reduction. This behavior indicates that, despite relatively high packet delivery ratios, the effective data rate is negatively affected by increased routing activity, channel contention, and transient route unavailability.

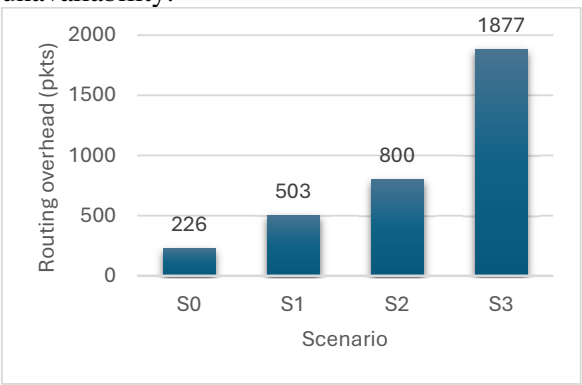


Fig. 4. AODV Control Packets vs Scenario

Routing overhead is the metric most strongly influenced by mobility. The total number of control packets generated by the Ad hoc On-Demand Distance Vector (AODV) protocol increases sharply from 226 packets in the static scenario to 1877 packets under high mobility. This super-linear growth highlights the dominant cost of route maintenance in highly dynamic environments. Frequent route

discoveries and error notifications consume a substantial portion of network resources, directly contributing to the observed increases in delay and reductions in throughput.

Overall, the results reveal a clear trade-off between connectivity gains and control cost. While moderate mobility improves packet delivery, higher mobility levels lead to increased latency, reduced throughput, and rapidly growing routing overhead. These findings confirm that MANET performance is governed by distinct operational regimes and underline the importance of anticipating mobility-induced effects when designing and deploying infrastructure-less networks.

6. PERFORMANCE PREDICTION MODEL

6.1 Empirical Trend Modeling

To convert the discrete scenario outcomes into a lightweight predictive layer, simple curve-fitting models are introduced for two metrics that exhibit clear monotonic behavior: end-to-end delay and routing overhead. The independent variable is the scenario-level average node speed v, approximated as $v=\{0, 3, 7.5, 1\}$ m/s for scenarios S0-S3, respectively.

End-to-end delay shows an approximately increasing trend with mobility; therefore, a first-order linear model is adopted:

$$Delay(v) = av + b \quad (3)$$

Routing overhead increases sharply with mobility, suggesting a non-linear dependency. A simple exponential form is used as an empirical approximation:

$$Overhead(v) = \alpha e^{\beta v} \quad (4)$$

The fitted parameters are obtained from the simulation data using least-squares estimation (linear regression for (3) and log-linear regression for (4)). The purpose of these models is not to provide an exact analytical characterization, but to obtain compact predictive relationships that capture the observed trend direction and magnitude under the fixed configuration of this study.

6.2 Predictive Validation

A minimal validation is performed by fitting the models using scenarios S0–S2 and predicting the metric values for the unseen scenario S3 ($v=15$ *m/s*). Table 2 reports the predicted values, the simulated values, and the relative error.

Table 2.

Predictive validation (fit on S0–S2, test on S3)

Metric	Predicted (S3)	Simulated (S3)	Relative Error
End-to-end delay (ms)	35.20	29.35	19.9%
AODV overhead (ctrl pkts)	2960	1877	57.7%

The results show that simple models can capture the general trend, while prediction accuracy is limited when extrapolating to highly dynamic regimes using only a small number of scenarios. This is expected because mobility-driven MANET behavior is strongly non-linear and configuration-dependent, and because the current study provides only four scenario points. Nevertheless, the presented modeling step supports the paper's objective of moving from isolated scenario reporting toward empirical, trend-based prediction.

In terms of limitations, the predictive models and numerical coefficients are specific to the present configuration: a single routing protocol (AODV), a fixed node density and deployment size, a single traffic model (CBR over UDP), and a single mobility model (random waypoint with scenario-specific speed ranges and pause times). Extending the approach to additional protocols, densities, traffic profiles, and multiple random seeds would improve generality and reduce extrapolation error.

7. CONCLUSION

This paper investigated the relationship between node mobility and MANET performance through a controlled set of GloMoSim simulations. By maintaining identical network, routing, and traffic configurations across all scenarios and varying only the mobility parameters, the study isolated the impact of node movement on packet

delivery, delay, throughput, and routing overhead.

The results demonstrate that mobility induces structured and reproducible trends rather than purely random behavior. Packet delivery benefits from moderate mobility and reaches a saturation region, while end-to-end delay increases steadily as route stability degrades. Throughput decreases under highly dynamic conditions, and routing overhead grows rapidly, becoming the dominant cost factor at high mobility levels. These coupled effects reveal clear operational regimes ranging from stable to highly dynamic network behavior.

Building on these observations, the paper proposed a lightweight, simulation-driven prediction framework that interprets multiple runs as samples of a continuous performance surface. Instead of treating each scenario as an isolated case, mobility becomes an input variable that drives expected performance trends. The resulting empirical rules enable practitioners to anticipate whether a given MANET configuration will operate in a stable, transitional, or highly dynamic regime and to estimate the associated trade-offs between reliability, latency, and control cost.

While the study is limited to a single routing protocol, node density, and traffic model, the methodology is general and reproducible. Future work will extend the framework to additional routing protocols, larger network scales, multiple random seeds, and heterogeneous traffic patterns. Incorporating automated curve fitting or machine learning techniques may further refine the predictive capability. Nonetheless, the presented approach demonstrates that meaningful performance prediction can be derived directly from structured simulation experiments, providing practical guidance for the design and evaluation of dynamic, infrastructure-less networks.

8. REFERENCES

[1] C. Nemade and U. Pujeri, *Comparative study and performance analysis of MANET routing protocol*, Int. J. Electr. Comput. Eng. Syst., vol. 14, no. 2, pp. 1–10, 2023, doi:10.32985/ijeces.14.2.4.

[2] G. Walunjkar and K. Anne, *Performance analysis of routing protocols in MANET*, Indones. J. Electr. Eng. Comput. Sci., vol. 17, no. 2, pp. 1047–1052, 2020, doi:10.11591/ijeecs.v17.i2.pp1047-1052.

[3] S. Seth, M. Mittal, and R. Dutta, *Unveiling the dynamics of Mobile Ad Hoc Networking (MANET)*, Int. J. Tech. Res. Sci., Special Issue ISET 2024, 2024, doi:10.30780/specialissue-iset-2024/027.

[4] T. Jaiswal and N. Kidwai, *MANETs: Challenges and future research scope*, Int. J. Eng. Adv. Technol., vol. 12, no. 2, pp. 1–6, 2022.

[5] X. Liu and S. Fujita, *Reliable low-latency multicasting in MANET: A DTN7-driven pub/sub framework optimizing delivery rate and throughput*, Information, vol. 16, no. 6, 2025, doi:10.3390/info16060508.

[6] I. Selim, N. Abdelrehem, W. Alayed, H. Elbadawy, and R. Sadek, *MANET routing protocols' performance assessment under dynamic network conditions*, Appl. Sci., vol. 15, no. 6, 2025, doi:10.3390/app15062891.

[7] B. Suleiman, G. Zimbele, and U. Yahaya, *Performance analysis of AODV and DSDV routing protocol in MANET*, J. Basics Appl. Sci. Res., vol. 3, no. 3, 2025.

[8] Q. Razouqi, A. Boushehri, M. Gaballa, L. Alsaleh, and M. Abbod, *Extended comparison and performance analysis for mobile ad-hoc networks routing protocols based on different traffic load patterns and performance metrics*, Electronics, vol. 13, no. 14, 2024, doi:10.3390/electronics13142877.

[9] A. Dak, R. Ruslan, A. Taib, and N. Radzi, *Performance analysis of non-realistic routing protocol using random waypoint model in MANET*, AIUB J. Sci. Eng., vol. 23, no. 1, 2024, doi:10.53799/ajse.v23i1.1025.

[10] N. Sarkar and M. Ali, *A study of MANET routing protocols in heterogeneous networks: A review and performance comparison*, Electronics, vol. 14, no. 5, 2025, doi:10.3390/electronics14050872.

[11] L. Hogie, P. Bouvry, and F. Guinand, *An overview of MANETs simulation*, Electron.

Notes Theor. Comput. Sci., vol. 150, pp. 81–101, 2006, doi:10.1016/j.entcs.2006.04.038.
[12] S. Chavan, A. Khandare, and S. Kachare, *Performance analysis of AODV and DSDV*, Procedia Comput. Sci., vol. 79, pp. 835–844, 2016.
[13] Z. Ismail and R. Hassan, *A performance study of various mobility speed on AODV routing protocol in homogeneous and heterogeneous MANET*, in Proc. Int. Conf. Computer and Communication Engineering (ICCCE), Kuala Lumpur, Malaysia, July 2010, pp. 1–6.
[14] N. A. Mahiddin and N. I. Sarkar, *Improving the performance of MANET gateway selection scheme for disaster recovery*, in Proc. IEEE Int. Conf. High Performance Computing and Communications (HPCC/SmartCity/DSS), 2016, pp. 907–912, doi:10.1109/ICC.2016.7511084.
[15] D. Sharma and S. Kumar, *Performance evaluation of MANETs with variation in transmission power using ad-hoc on-demand multipath distance vector routing protocol*, Int. J. Comput. Appl., vol. 97, no. 4, pp. 1–7, 2014, doi:10.5120/18210-3483.
[16] D. Ma, S. Subasree, and N. K. Sakthivel, *Performance analysis of efficient energy routing protocols in MANET*, Procedia Comput. Sci., vol. 57, pp. 890–897, 2015, doi:10.1016/j.procs.2015.07.418.

Predicția performanței rețelelor MANET pe baza simulărilor GloMoSim în funcție de mobilitatea nodurilor

Rezumat*:* Rețelele Mobile Ad Hoc (MANET – Mobile Ad Hoc Network) funcționează în medii dinamice, în care mobilitatea nodurilor modifică permanent topologia rețelei. Deși studiile bazate pe simulare oferă numeroase măsurători de performanță, majoritatea rămân descriptive și nu permit anticiparea comportamentului rețelei. Această lucrare propune o abordare ușoară, bazată pe simulare, pentru derivarea unor tendințe predictive. Folosind GloMoSim, sunt definite patru scenarii în care toți parametrii sunt constanți, cu excepția mobilității. Utilizând AODV și trafic CBR peste UDP, sunt analizate rata de livrare, întârzierea, debitul și overhead-ul de rutare, evidențiindu-se relații structurate între mobilitate și performanță.

Robert-Marian PAPA, Eng., "Nicolae Bălcescu" Land Forces Academy of Sibiu, Department of Telecommunications, IT and Cyber Security, Faculty of Military Management, Master Student, Technical University of Cluj-Napoca, Faculty of Electronics, Telecommunications and Information Technology, papa.ma.robert@student.utcluj.ro, +40 269 432 990, 3-5 Revolutiei Street, Sibiu, Romania.
Ioana-Claudia ENACHE, Eng., Master Student, Technical University of Cluj-Napoca, Faculty of Electronics, Telecommunications and Information Technology, enache.li.ioana@student.utcluj.ro, +40 269 432 990, 3-5 Revolutiei Street, Sibiu, Romania.
Annamaria SÂRBU, PhD, Associate Professor, "Nicolae Bălcescu" Land Forces Academy of Sibiu, Department of Telecommunications, IT and Cyber Security, Faculty of Military Management, sarbu.annamaria@armyacademy.ro, +40 269 432 990, 3-5 Revolutiei Street, Sibiu, Romania.